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A STUDY OF THE DECAY $K_L^o \to \pi\mu\nu$ *

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ABSTRACT

We report results from a Dalitz plot analysis of 16386 $K^{o}_{\mu 3}$ candidates obtained in an experiment with high efficiency across the Dalitz plot and very low background. We measure the vector and scalar form factors and obtain the following values for the linear expansion parameters: λ_{+} = 0.028 ± 0.011, λ_{o} = 0.039 ± 0.010.

We report results from a new study of the form factors describing the decay $K_L^o \to \pi^{\pm}\mu^{\mp}\nu(K^o_{\mu3})$. This experiment compares favorably to other recent experiments of comparable or higher statistical precision [1-3] in that it has extremely high and uniform efficiency across the Dalitz plot and extremely low background ($\lesssim$ 0.3%) from other decay modes. Results on the $K_L^o \to \pi^+\pi^-\pi^o(K_{3\pi})$ decay and $K_L^o \to \pi^{\pm}e^{\mp}\nu(K^o_{e3})$ decay measured in the same apparatus, have been previously reported [4,5].

The detector used was the SLAC 2 meter streamer chamber [6] shown schematically in fig. 1. The trigger and scanning criteria, common for all decay modes, have been described elsewhere [5]. Time of flight and pulse height were recorded for four groups of scintillation counters (A,B,C and D in fig. 1), with the signals from the muon hodoscope (H) being latched. Both legs of every Vee within the central region of the streamer chamber and the highest momentum track emerging from each shower plate were measured and geometrically reconstructed using a version of TVGP modified to constrain each decay track to have originated from a common vertex. The momentum resolution obtained was (1-2)% in typical cases. Using the time of flight data, which was measured on average to a standard deviation of 0.6 ns for $K^o_{\mu3}$ events, one-constraint kinematic fits were made to the $K^o_{\mu3}$, K^o_{e3} and $K^o_{3\pi}$ hypotheses. All Vees with vertex coordinates within a restricted fiducial volume with a fit probability for either $K^o_{\mu3}$ charge mode greater than 15% and a fitted K^o momentum in the range ($1500 \leq P_K \leq 4000$) MeV/c were subjected to further analysis.

Qualitatively, $K^o_{3\pi}$ background was eliminated by kinematics and K^o_{e3} background was eliminated by identification of the electron in the shower plates. Quantitatively, three cuts were made to ensure a pure $K^o_{\mu3}$ sample:

(1) Both decay tracks were required to have a change in angle in the shower plate consistent with multiple scattering and a change in energy such that $\Delta E/\sigma(\Delta E) < 10$ where ΔE is the energy loss above that expected from mean dE/dx. This cut reduces the K^o_{e3} contamination to $\sim$0.2% which is essentially the probability that an electron retains 80% of its energy in traversing the shower plate.

(2) Events with $K^o_{3\pi}$ fit probability > 1% were rejected, reducing the $K^o_{3\pi}$ contamination to the $\sim$0.1% level as determined by Monte Carlo simulation of the $K^o_{3\pi}$ decay mode.

(3) Both decay tracks were required to have a momentum in the range $150 \leq P \leq 2500$ MeV/c.[‡1]

A data sample of 20,420 events survived these cuts. No subtraction of the small K^o_{e3} and $K^o_{3\pi}$ backgrounds were made in the subsequent analysis.

The Dalitz plot of T_π vs. T_μ was divided into 15 by 15 MeV wide bins and, in order to reduce reliance on Monte Carlo simulation of measurement errors, only those bins not touching the Dalitz plot boundary were retained. Approximately 20% of the data had both charge mode solutions outside this restricted region and were excluded from the final data sample. By combining information from kinematics and from the muon counters, the charge mode ambiguity could be partially resolved. If either charge mode fit probability was below a minimum value, chosen as 5%, the interpretation was rejected.[‡2] This allowed a "unique" interpretation of 28% of the data. Another 20% either had both solutions within the same bin on the Dalitz plot or one solution in the excluded region near the Dalitz plot boundary.[‡3] Finally, the muon counter hodoscope allowed muon identification for 10% of the events.[‡4] Overall, 16,386 events were retained for final analysis of which 55% had a unique representation on the Dalitz plot. Maximal information is extracted from our data by performing a Dalitz plot fit for the "unique" events and a fit to the neutrino energy spectrum for the charge mode ambiguous events.[‡5]

In the context of a V-A theory describing the $K^o_{\mu 3}$ decay, the hadronic current has the form $J_\alpha \sim f_+(t)\ (P_K + P_\pi)_\alpha + f_-(t)(P_K - P_\pi)_\alpha$. Historically, determination of $f_+(t)$ and $\xi_-(t) = f_-(t)/f_+(t)$ have been made to test some strong interaction models, but comparison with theory is facilitated by measurement of $f_+(t)$ and the "induced scalar" form factor $f_o(t) = f_+(t) + [t/m_K^2 - m_\pi^2)]\ f_-(t)$. We have chosen to perform a model dependent analysis by expressing both the Dalitz plot and neutrino energy spectra as functions of the conventional linearized version of these form factors:

$$f_+(t) = f_+(0)\ (1 + \lambda_+ t/m_\pi^2), \quad f_o(t) = f_o(0)\ (1 + \lambda_o t/m_\pi^2),$$

with $f_o(0) = f_+(0)$. The linear expansion parameters λ_+ and λ_o were determined by minimizing χ^2 where χ^2 is given by the sum of two statistically independent terms, χ^2 (Dalitz plot) and χ^2 (neutrino energy). The number of events in each bin of the Dalitz plot and the neutrino energy spectrum were corrected by efficiencies obtained from a Monte Carlo calculation.[‡6] We obtain from this analysis $\lambda_+ = 0.028 \pm 0.011$ and $\lambda_o = 0.039 \pm 0.010$ with $\chi^2/DF = 39/47$.[‡7] Error contours corresponding to $\Delta\chi^2 = 1$ (39.4% C.L.) and 90% C.L. are shown in fig. 2. Independently minimizing the χ^2 of each subsample obtains $\lambda_+ = 0.027 \pm 0.012$, $\lambda_o = 0.041 \pm 0.012$ from the unique events and $\lambda_+ = 0.032 \pm 0.025$, $\lambda_o = 0.032 \pm 0.022$ from the ambiguous class.

Values of $f_+(t)$ and $f_o(t)$, in bands of fixed t, may be obtained by making a fit to the muon energy dependence. We show the results of such a procedure in fig. 3 for the 55% of our data in which values of t are well defined. Although the $f_+(t)$ and $f_o(t)$ distribution obtained by this model independent procedure do not have compelling statistical precision, they show consistency with the use of linearized from factors. Fig. 3 [a] also shows the high geometric efficiency of our apparatus.

In order to verify that our apparatus is well understood, we have made numerous detailed comparisons between data and Monte Carlo. Fig. 4 shows the decay distribution along the beam direction, a particularly sensitive example of the many distributions which have been compared and found to be in excellent agreement. Another important comparison is the number of events (1.2%) excluded by the $K^o_{3\pi}$ probability cut, which verifies the low level of this contamination. A test for anomalous K^o_{e3} contamination can be made directly from the data utilizing the expectation that any electrons present would lie in the tail of the $\Delta E/\sigma(\Delta E)$ distribution. Making the cut $\Delta E/\sigma(\Delta E) \leq 3$ (which contains 82% of the data) shows no effect on the value of the form factors. In the search for systematic effects, various statistically independent subsamples including low P_K versus high P_K, upstream vertices versus downstream vertices, and inbending tracks versus outbending tracks have been compared. No effects were found which were not negligible in comparison with our statistical error.

Finally, our result for the form factors, $\lambda_+ = 0.028 \pm 0.011$ and $\lambda_o = 0.039 \pm 0.010$, are in good agreement with recent experiments [1-3], with the Callan-Treiman prediction of $\lambda_o = 0.021 \pm 0.003$ [7], and with μ-e universality.

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FOOTNOTES

ǂ1 This cut was dictated by kinematic limitations in the $K^o_{3\pi}$ decay mode. The Monte Carlo program was required to simulate the behavior of pions, electrons and muons in the shower plates over this momentum range. A more detailed description of the simulation is given in ref. [5].

ǂ2 Monte Carlo studies indicated that this procedure chose the correct solution 96% of the time. The minimum probability required was varied between 5% and 15% with no effect on the results.

ǂ3 This latter class of events enter the Dalitz plot analysis with weight 0.5.

ǂ4 Although the muon hodoscope nominally subtended 18% of the $K^o_{\mu 3}$ solid angle, we chose to interrogate the hodoscope only for a restricted (forward) solid angle in order to avoid hodoscope edges and the necessity of tracking both data and Monte Carlo tracks through the poorly determined magnetic fringe field. The effects of pion decay and punch-through were determined from the $K^o_{3\pi}$ sample to be $\sim$8% and were simulated in the Monte Carlo. The 10% ambiguity resolution quoted in the text is not mutually exclusive of the resolution obtained from kinematics.

ǂ5 In these events, the average value of the neutrino energy given by the two solutions was used in the fitting. The difference in the two neutrino energy values is typically $\lesssim$ 1 MeV compared to the 10 MeV bin size used in the analysis.

FOOTNOTES

‡6 Monte Carlo "data" were generated in the same format as experimental data and passed through the same reconstruction and kinematics programs. The efficiencies are not strictly geometeric in that account is taken of migration on the Dalitz plot due to measurement errors and the wrong sign charge mode choice.

‡7 We have explored the region $-0.3 \leq \lambda_+ \leq 0.3$, $-0.3 \leq \lambda_o \leq 0.3$ in a search for a second minimum of χ^2 as reported by Albrecht et al. [2]. We find only one minimum in this region.

REFERENCES

[1] G. Donaldson, D. Fryberger, D. Hitlin, J. Liu, B. Meyer, R. Piccioni, A. Rothenberg, D. Uggla, S. Wojcicki, D. Dorfan, Phys. Rev. D9 (1974) 2960.

[2] K.-F. Albrecht, F. Deak, V. Genchev, T.S. Grigalashvili, B.N. Guskov, J. Hladky, I.M. Ivanchenko, V.P. Kekelidze, D. Kiss, V.G. Krivokhizhin, V.V. Kuhtin, M.F. Likhachev, P. Major, A. Meyer, E. Nagy, M. Novak, A. Prokes, H.-E. Rysek, Yu. I. Salomatin, I.A. Savin, L.V. Sil'vestrov, V.E. Simonov, G.G. Takhtamyshev, P. Todorov, L. Urban, G. Vesztergombi, A.S. Vovenko, Phys. Lett. 48B (1974) 393.

[3] C.D. Buchanen, D.J. Drickey, D.M. Pepper, F.D. Rudnick, P.F. Shepard, E. Dally, P. Innocenti, E. Seppi, C.-Y. Chien, B. Cox, L. Ettlinger, L. Resvanis, R. Zdanis, Phys. Rev. D11 (1975) 457.

[4] D.G. Hill, M. Sakitt, G.R. Snape, A.J. Stevens, J. Park, L.C. Wang, D.N. Slone, K. O., Bunnell, R.F. Mozley, A.C. Odian, W.P. Swanson, F. Villa, F.F. Liu, XVII International Conf. on High Energy Physics, London, III-16 1974. See also D.N. Slone, Ph.D. Thesis, Stanford University (1974).

[5] D.G. Hill, M. Sakitt, G.R. Snape, A.J. Stevens, K.O. Bunnell, R.F. Mozley, A.C. Odian, J. Park, D.N. Slone, W.P. Swanson, F. Villa, L.C. Wang and F.F. Liu, Phys. Lett. 73B (1978) 483.

[6] F. Bulos, A. Odian, F. Villa, D. Yount, SLAC Report 74 (1967).

[7] C.G. Callan and S.B. Treiman, Phys. Rev. Lett. 16 (1966) 153; and R. Dashen and M. Weinstein, ibid. 22 (1969) 1337.

FIGURE CAPTIONS

Fig. 1 Top view of the streamer chambers and counter. Figure is not to scale. See ref. [6] for details.

Fig. 2 Fitted values for the linear expansion parameter obtained from the analysis described in the text.

Fig. 3 (a) The $f_+(t)$ distribution for a subset of the data. The solid line ($\lambda_+ = 0.028$) is not a fit to these distributions but results from the analysis described in the text. Also shown (dashed line, right hand scale) is the geometric efficiency as a function of t.

(b) The $f_o(t)$ distribution. Solid line corresponds to $\lambda_o = 0.039$.

Fig. 4 The decay vertex distribution along the beam direction.

1	10-249-78
2	11-1379-78
3a	10-253-78
3b	10-251-78
4	10-250-78

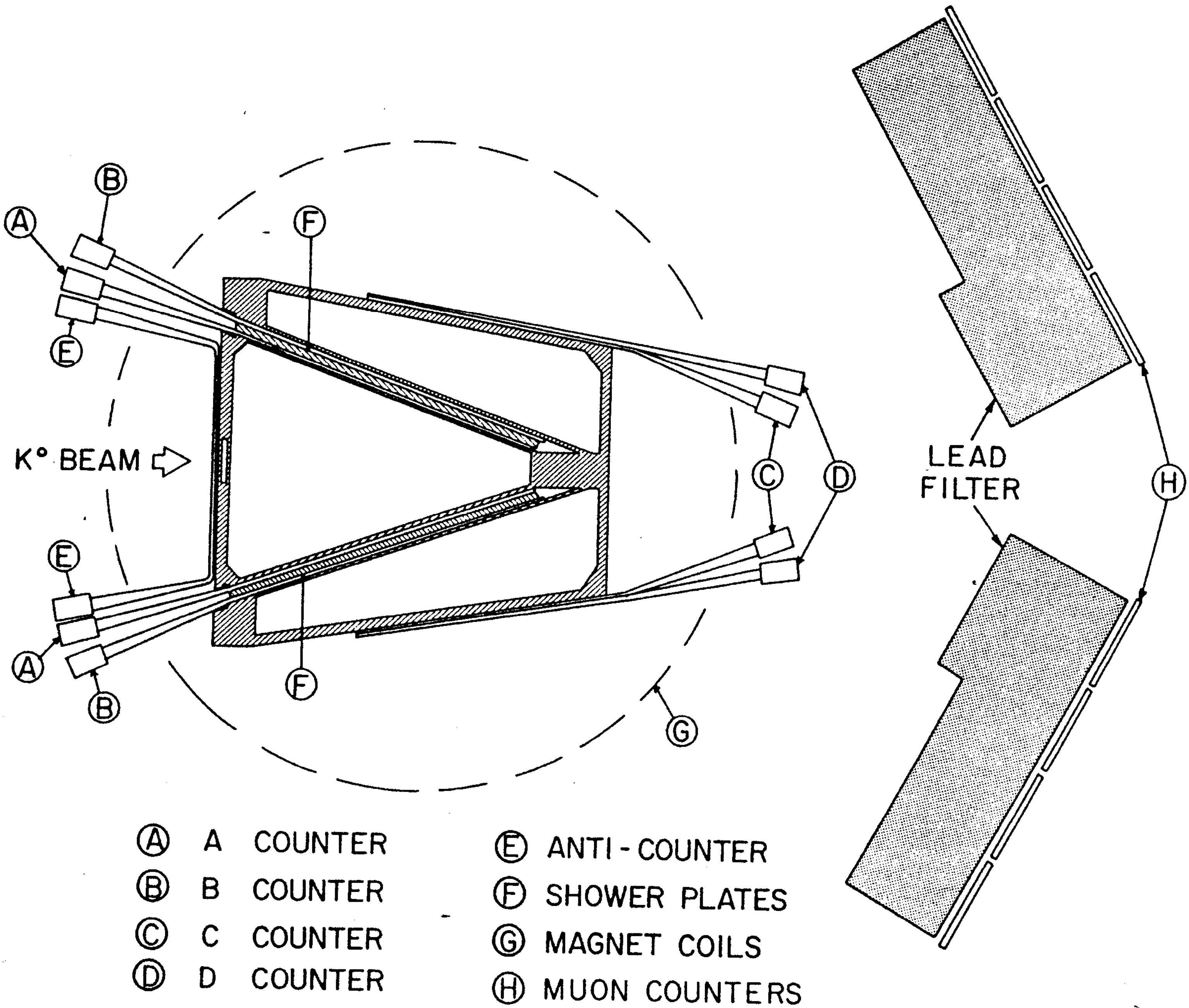

A
B
E
F
K° BEAM
C
D
G
LEAD FILTER
H
A A COUNTER
B B COUNTER
C C COUNTER
D D COUNTER
E ANTI - COUNTER
F SHOWER PLATES
G MAGNET COILS
H MUON COUNTERS

Fig. 1

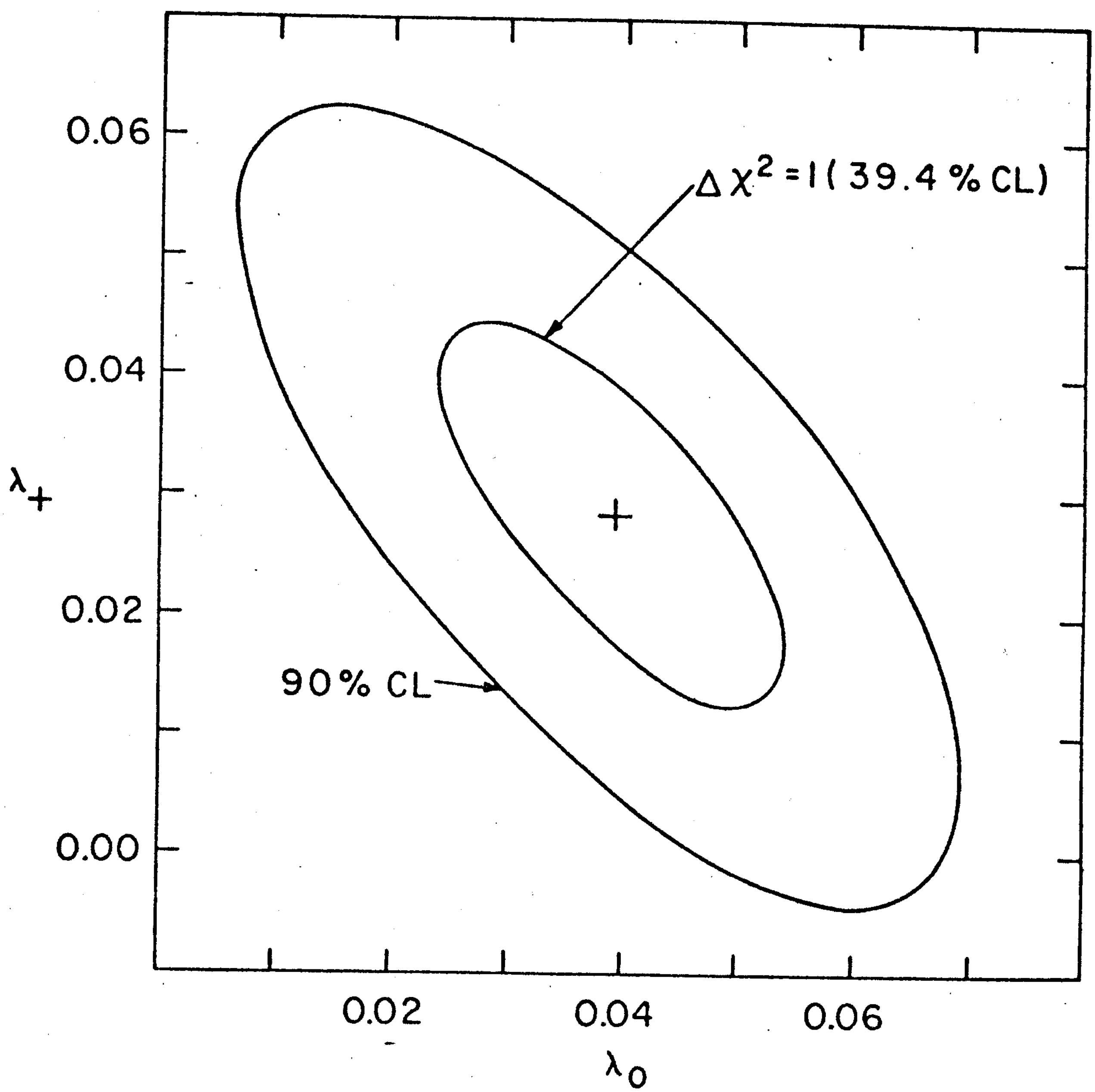
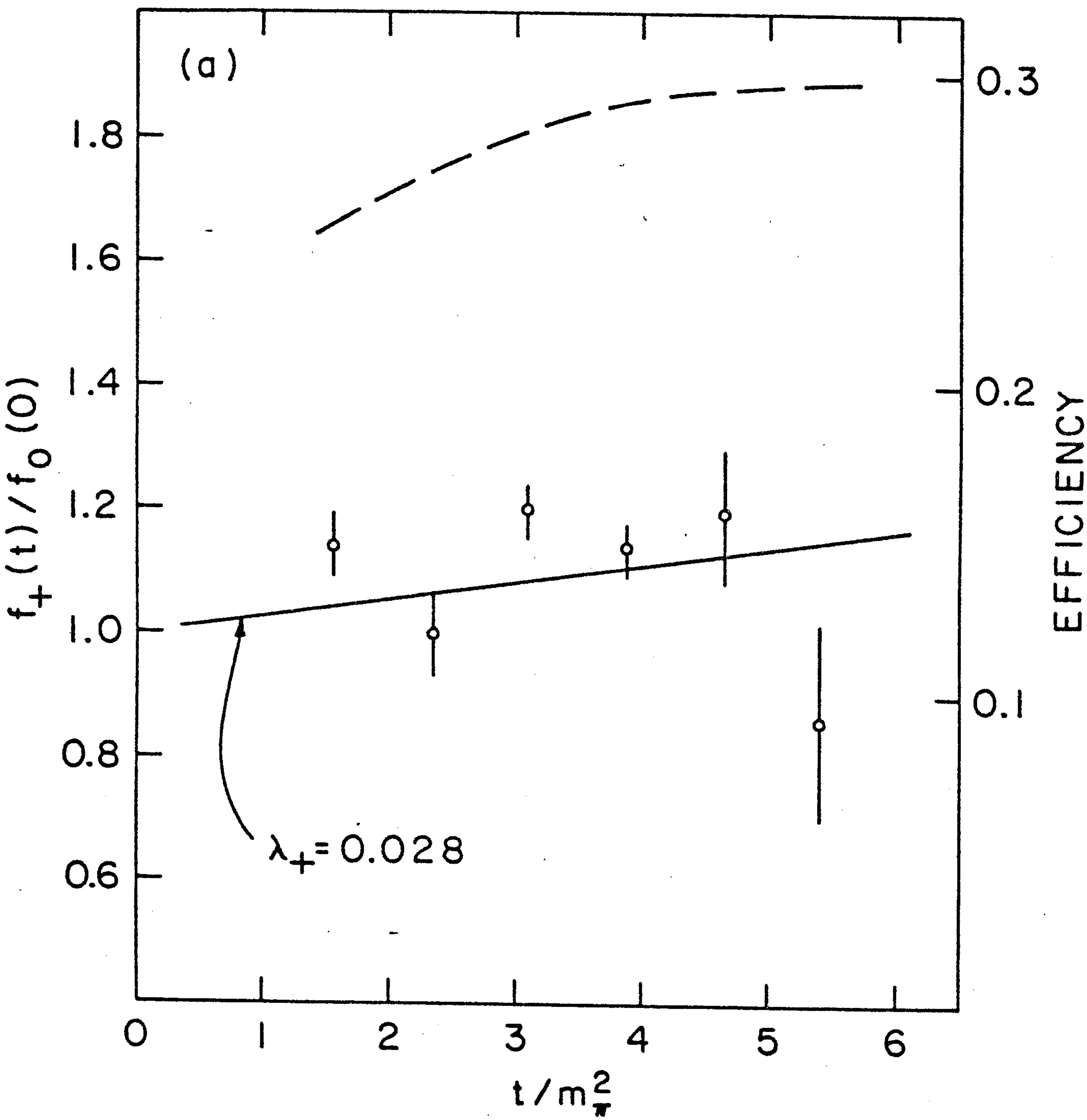

0.06
0.04
0.02
0.00
λ_+
$\Delta\chi^2 = 1$ (39.4 % CL)
90% CL
0.02
0.04
0.06
λ_0

Fig. 2



(a)
1.8
1.6
1.4
1.2
1.0
0.8
0.6
$f_+(t)/f_0(0)$
0.3
0.2
0.1
EFFICIENCY
$\lambda_+ = 0.028$
0
1
2
3
4
5
6
t/m_π^2

Fig. 3a

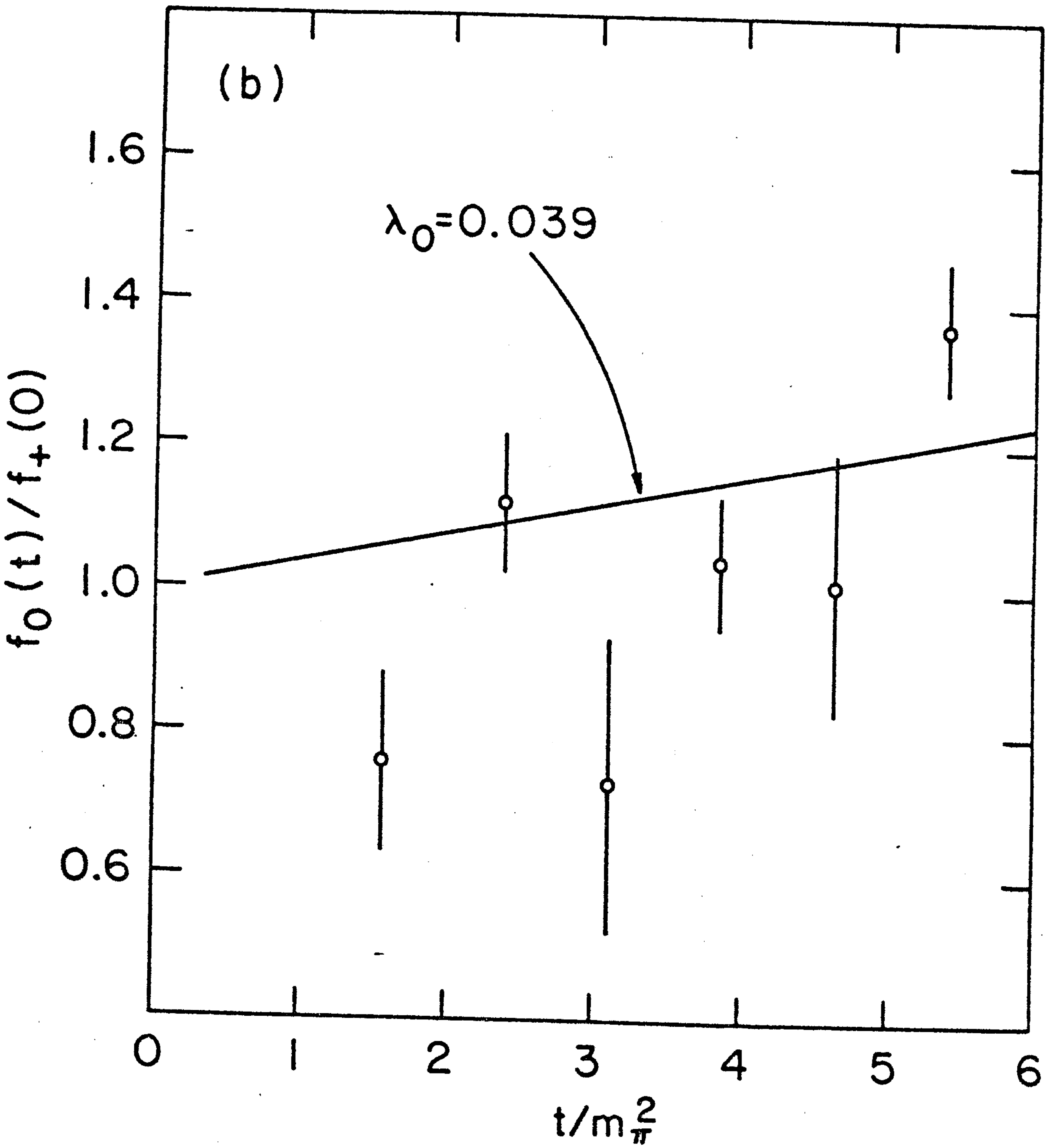
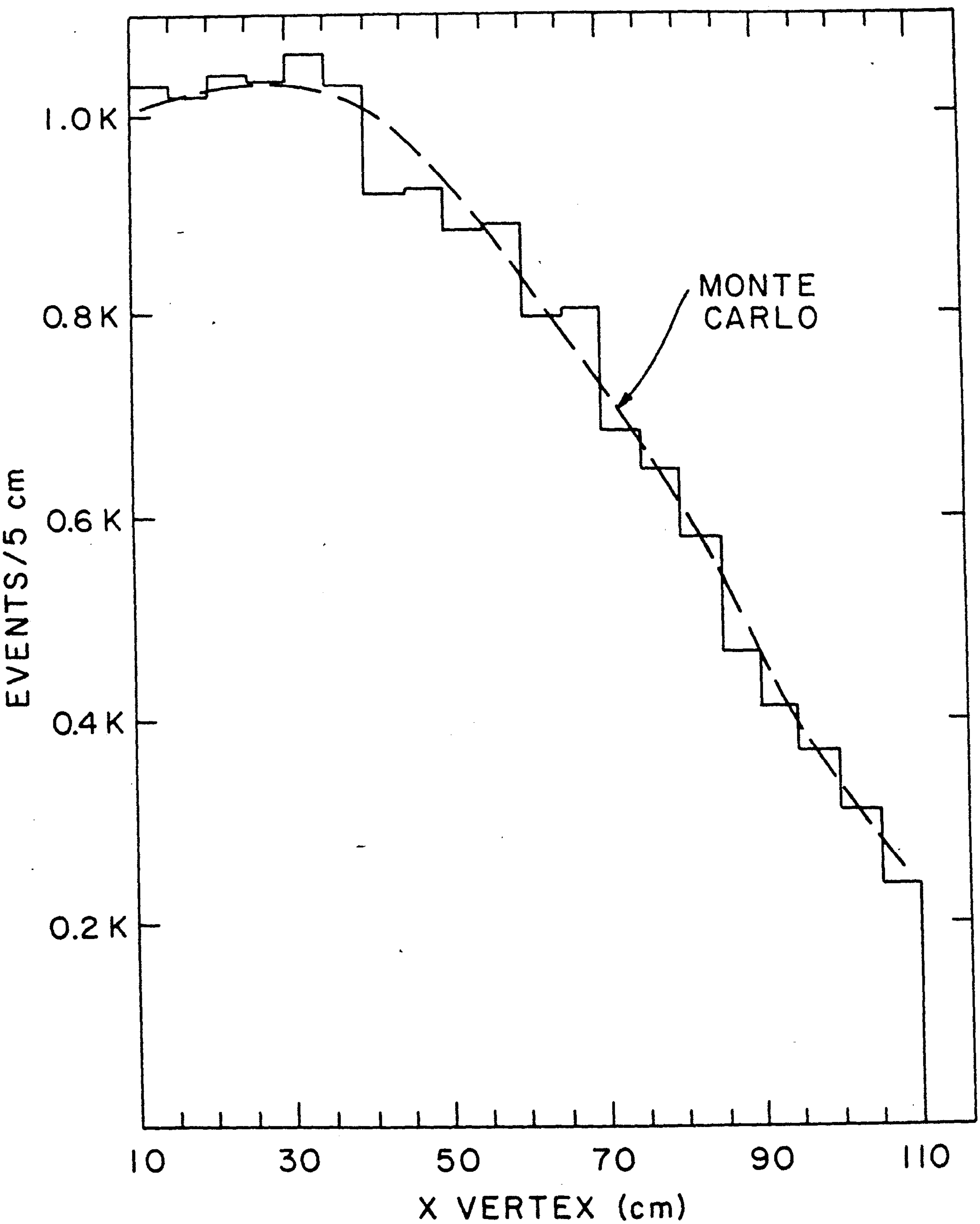


Fig. 3b



MONTE
CARLO
1.0 K
0.8 K
0.6 K
0.4 K
0.2 K
EVENTS/5 cm
10
30
50
70
90
110
X VERTEX (cm)